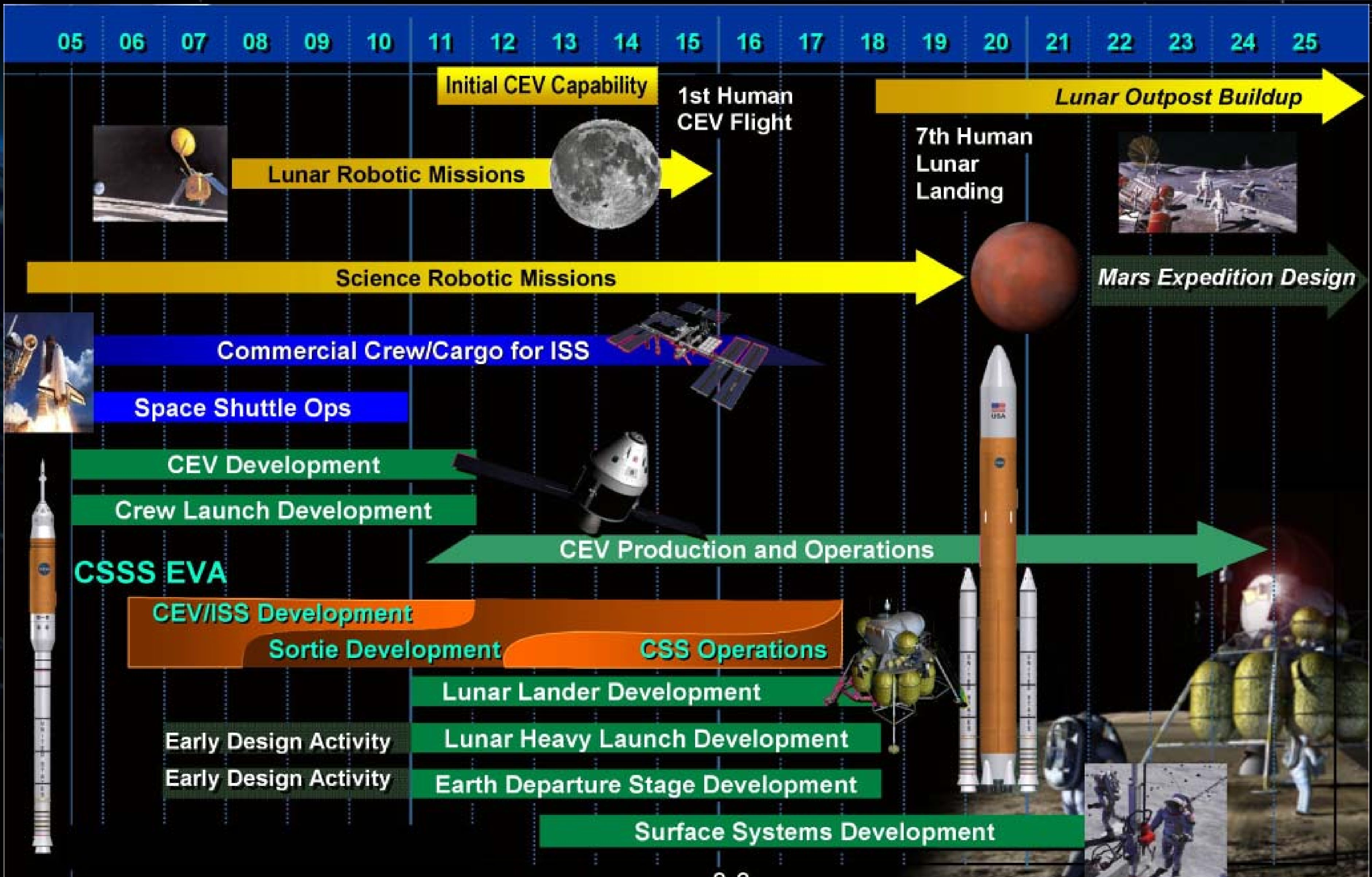
Autonomy & Mission Operations

Dr. David J. Korsmeyer
Intelligent Systems Division

NASA's Exploration Roadmap



NASA Mission Types

1. Grandfather Clocks
   - Large, complex, awe-inspiring, handmade, expensive
   - Similar to traditional manned space missions
2. Swiss Clocks
   - Smaller, elaborate, intricate, & exceptionally well engineered
   - Similar to traditional unmanned robotic science missions
3. Quartz Watches
   - Many, reliable, robust, limited mechanical function
   - Majority of the capabilities are in the software
   - **Small Sats are desired to be a lot like these…**

Effective SmallSats

- Small Sats support “Efficient & Effective Science” by enabling a rapid set of Missions via:
  - Common spacecraft bus and hardware interfaces for rapid manufacturing and checkout
  - Common avionics to allow standard instrument and component integration
- Many current SmallSat efforts are focused upon the hardware and component issues
  - Lightweight components
  - Fast processors, etc.

Effective SmallSats (SmartSats)

- Need to utilize Common On-board and Mission Ops “Intelligent Software” to enable “SmartSats”
    - Function robustly in dynamic and uncertain environments
    - Support opportunistic and goal-directed science data acquisition
    - Support reduced mission operations requirements
    - Integrate via software, multiple low-cost instruments for “grade-A” science

Current Mission Ops

- ~10 people for each spacecraft
- No or limited on-board capability for system monitoring, diagnosis or recovery
- Operational commands must be sent from mission ops
- No goal-directed operations on board or in the GDS system

SmartSats Target

- 1 person for ~10 spacecraft (extreme case)
- Enable onboard planning, and execution (ala Deep Space 1) to achieve mission/science goals
- Enable onboard monitoring, diagnosis and recovery (ala EO-1) to ensure robust operation
- Enable smart-advisory and support automation for flight controllers to efficiently manage multiple systems (or missions)

Autonomy & Mission Operations

- Rapid Integration and deployment of robust mission software for new missions
  - Data-driven architectures to enable software code to be largely stable.
  - Advanced verification and validation of the software that does change.
  - Coupled to simulation-in-the-loop and hardware-in-the-loop

Autonomy & Mission Operations

- NASA Goal
  - Extend technologies and systems to enable smart small satellites with intelligent operations

SmartSat Exploration Challenges

- **Spacecraft autonomy**
  - Need: effective, reliable, goal-based operations of unmanned spacecraft
  - State of art: requires direct human command and monitoring
- **Spacecraft state management**
  - Need: effective, on-board management of unmanned spacecraft system health
  - State of art: requires direct monitoring, limited “safing” and on-board diagnostics
- **Lightweight mission operations**
  - Need: flexible, sustainable and “lights-out” mission operations paradigms
  - State of art : large numbers of flight controllers and staff

- Automation of existing spacecraft and ground systems is difficult and often impractical. Best to start from the beginning…

Autonomous Software, Algorithms & Data Management

Intelligent Automation

- Nomenclature: Automation versus Autonomy
  - Autonomy refers to placement of control:
    - Spacecraft autonomy specifies on-board autonomous control of spacecraft
    - Spacecraft being able to operate with less interaction with ground
  - Automation refers to level of human involvement in control and operations
    - Simple control loops are examples of automation
    - Automation is also use of software to reduce human involvement (decision support aids)

Intelligent Automation

- Technology:
  - Flexible and adaptable software supporting automation and autonomy
  - Providing adjustable levels of human involvement

- Key elements of technology:
  - Data-driven general and re-usable modules
  - Common data specification
  - Monitoring, analysis, diagnosis of telemetry and system states
  - Decision-making: From help for users to on-board decision-making
  - Execution: Carry out decisions and plans, from humans and automation
  - Human interaction support; adjustable automation, abstraction

Technical Challenges

- Human in loop
  - Traditional automation and autonomy software leave human out
  - Need software capable of working for or with human users
- Adjustability
  - Circumstances drive need for more or less human involvement
  - Need software with automation levels adjustable online
  - Same core capabilities used on ground and in flight
- Trust
  - Reluctance to accept flexible software
  - Need trust-building process and verification techniques
- Reality
  - Technology must handle the real world, which is messy
  - Need to develop software against real world situations
- Insertion path
  - Switching from manual to new automation is difficult and costly
  - Need software supporting gradually increasing automation

Remote Agent Experiment

Remote Agent Experiment

May 17-21, 1999

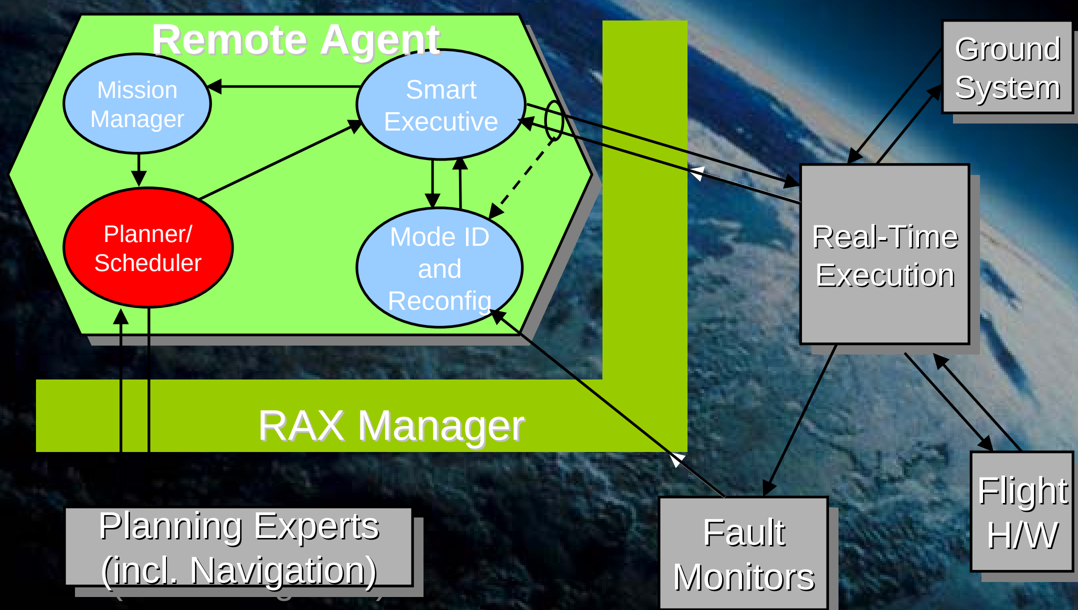
65 Million miles from Earth

During *Cruise Phase*

Remote Agent on DS1 wins NASA's 1999 Software of the Year

Completely Autonomous Operations for 5 days.

- Planning, Execution and Recovery



Ames Research Center

JPL

Carnegie Mellon

ALDER Technology Project

Autonomous Lander Demonstrator (ALDER)

- Technology Concept funded under Exploration Technology Development Program.

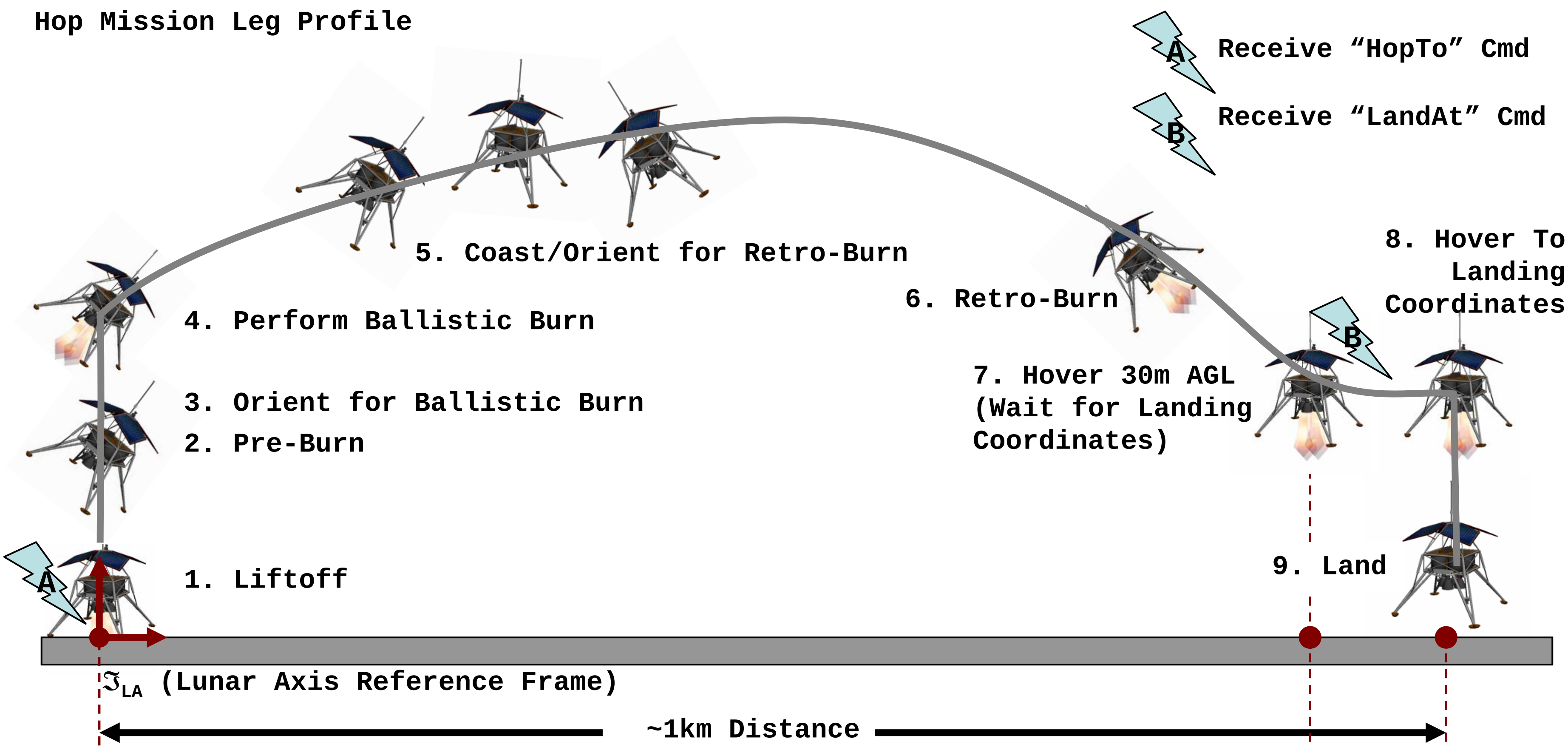
  (NOT A MISSION CONCEPT)

- The goal of ALDER was to demonstrate Autonomy Technologies in spacecraft by implementing;
- Autonomous operation of post-LEO phases (lunar injection, cruise phase, lunar landing and mobile surface ops).
- System health management for spacecraft state
- Adaptive control
- Vision and Image processing for position estimation

Mission Outline

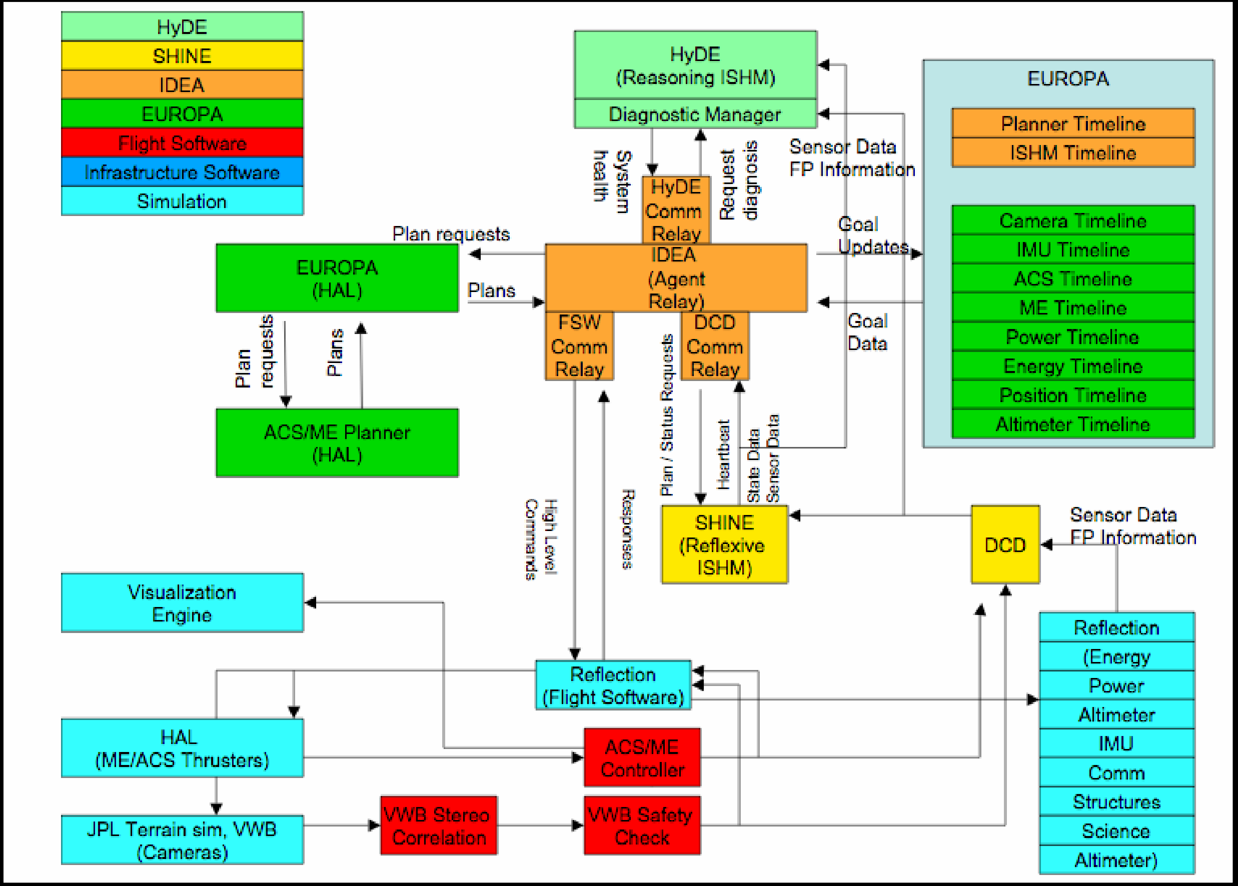
- Concept Mission Duration for 10-14 Days
- Controlled soft landing near equator on Earth side, landing in sunlight.
- Perform scientific measurements at landing site.
    - Number of possible goals, including rock/soil samples, spectrometers, ground penetrating radar, magnetometer measurements, seismometer, etc.
- “Hop” to next location, roughly 1km from last landing site.
    - Take off from surface
    - Lateral Transfer
    - Land
- Repeat scientific measurements, hop to the next site.

Hop Mission Profile



Autonomy Technologies

1. **EUROPA**: Planning and Execution
2. **HyDE**: Integrated System Health Management (ISHM)
3. **SHINE**: Reflexive ISHM
4. **IDEA**: Reasoning
5. **Vision Workbench**: Vision Processing and Stereo Image Correlation
6. **Reflection Architecture:** Guidance, Control and Simulation



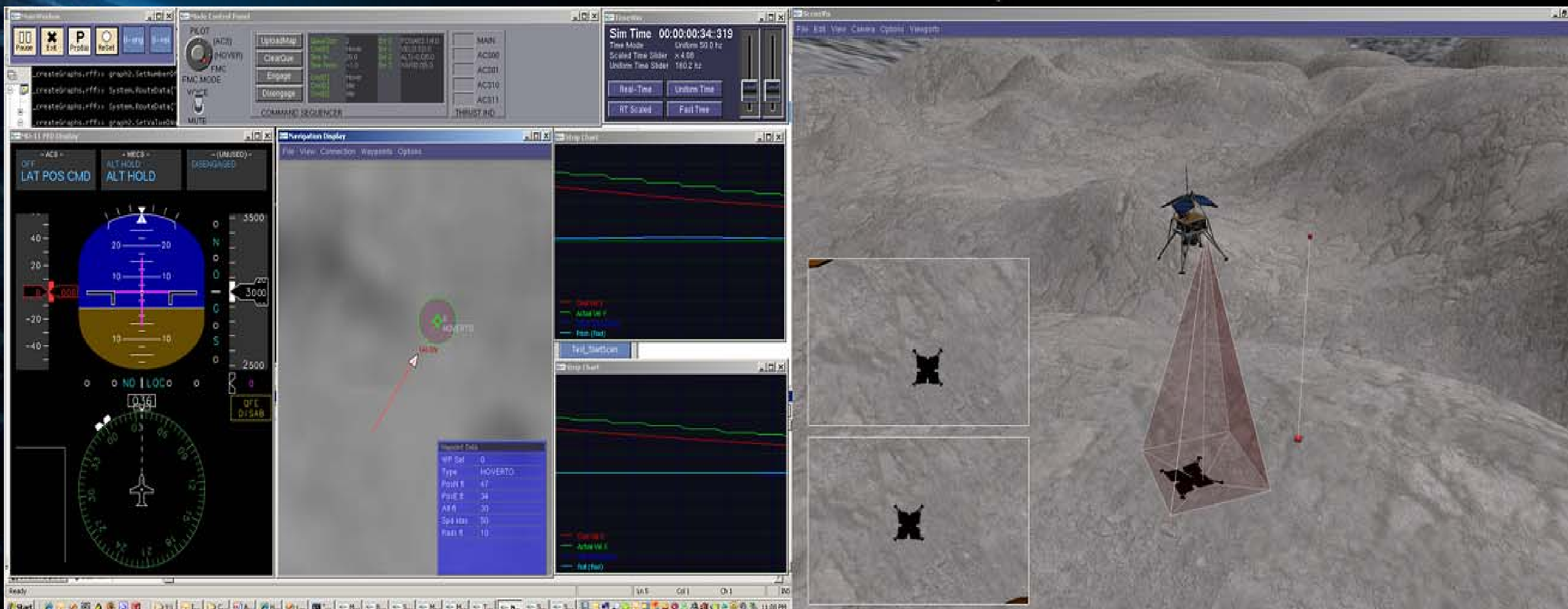
Simulation Environment

System Control Panel

FMC Mode Control Panel

System Time Window

Scene Visualization



Primary Flight Display

Navigatio n Display

Graphs

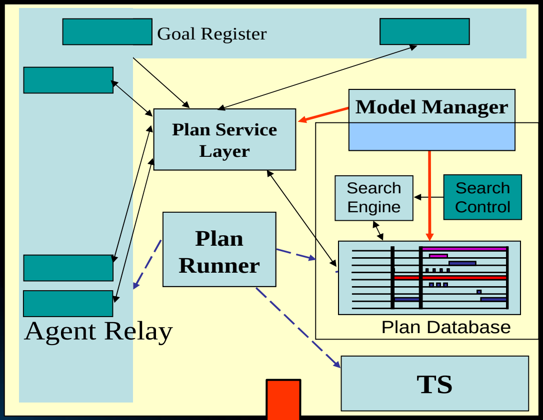
Stereo Camera Viewports

Intelligent Onboard Control

IDEA: Intelligent Deployable Execution Architecture

- Scaled for On-board Operations
- Coordinates execution of complex tasks
- Generic real-time coordination and inter-agent communications
- Application-specific, model-based definition of operational rules for nominal and off-nominal scenarios

IDEA



K9

Life in the Atacama

Integrated Systems Health Management

- The Livingstone 2 (L2) model-based diagnosis continuously monitors the health of the spacecraft camera and processor subsystems
- Advanced diagnostic module executed
  - Deployed on EO-1 in June - Sept 2004
- 15 successful diagnostic tests via data link
  - L2 successfully detected and isolated **All** of these simulated failures
  - Still Operational, and fully functioning on EO-1
- Clear application to Small Sats, CEV, CLV, and other new vehicles

"This software grants us the ability to troubleshoot the robotic systems required to handle increasingly complex tasks of exploration, while they are millions of miles and perhaps light years away from Earth."

Vision-based 3D Localization

Scope:

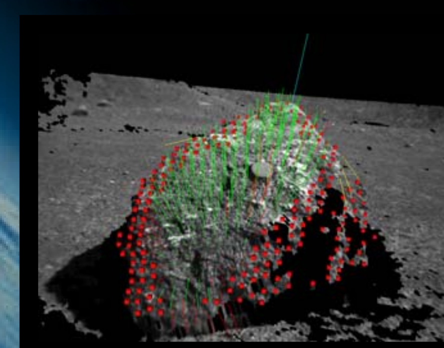
3D Navigation & Placement Issues:

- 3D visual navigation and estimation
- Robust, accurate visual tracking of target features
- Safe traverse over distances (hoppers, floaters) with local obstacle avoidance
- Target handoff between cameras
- Instrument placement location assessment
- Safe instrument motion planning and final placement

Existing Capability: TRL 7 Software/HW system

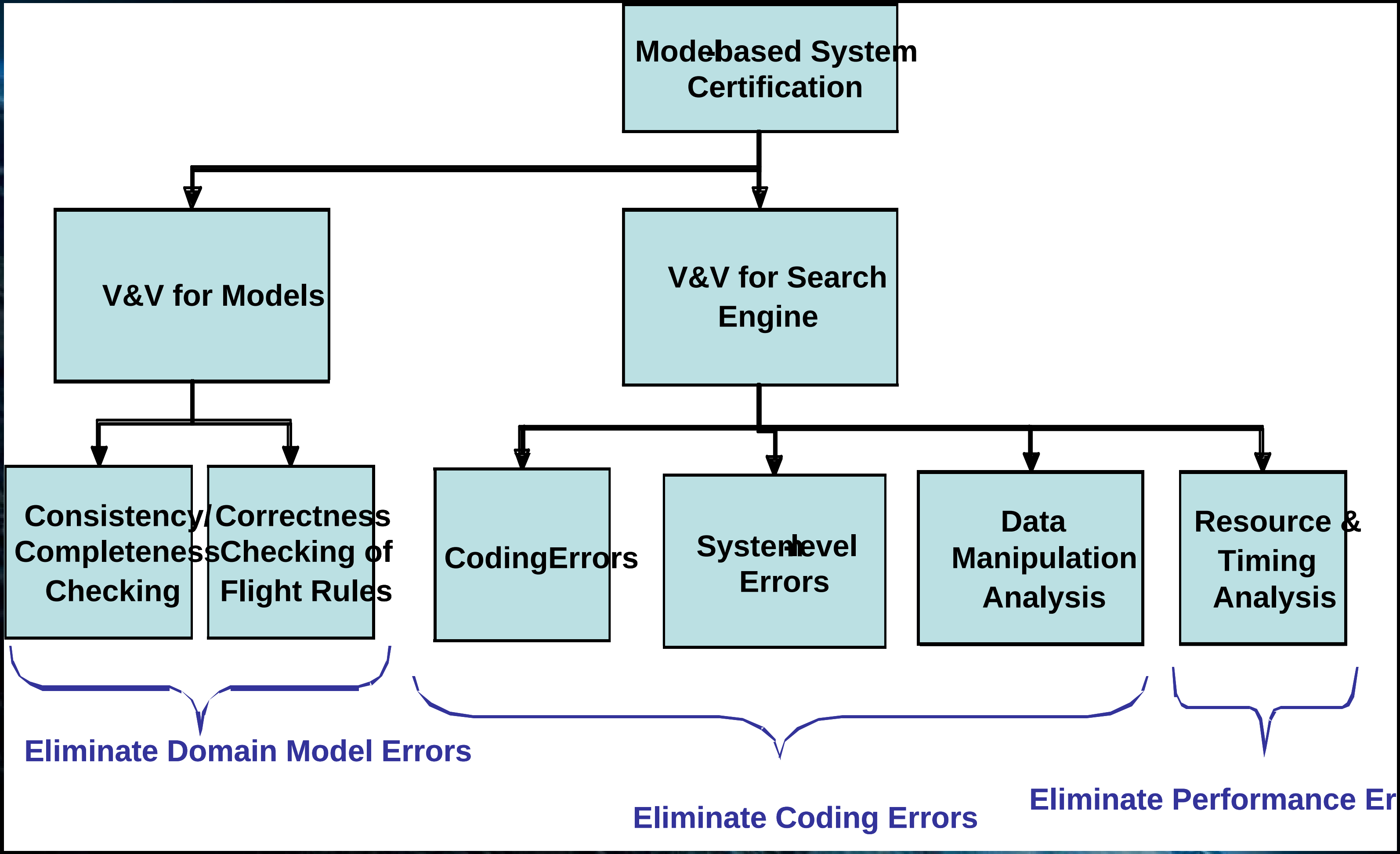
Mission Relevance:

- 3D Navigation and Instrument Placement
  - 3D Navigation
    - 3D Navigator
    - Visual Tracking
      - Feature Tracker
      - Handoff
  - Instrument Placement
    - Sampler Path Planning
    - Target Assessment
      - Segment Rock
      - Instrument Safety



Robust Autonomy Software for Missions

Certification and validation of Autonomy software

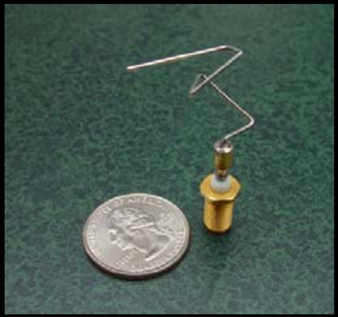


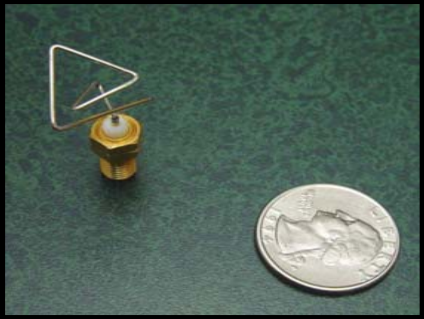
Evolved Antenna in ST5 Mission

Mission Infusion

Space Technology 5 Mission:
- New Millennium Program
- Sun-Earth Connection
- Run by GSFC
- Three nanosats, launch in CY2005
- Measure effect of solar activity on Earth's magnetosphere

ARC's Technology:
- ARC's software automatically designed ST5 antenna to meet mission requirements
- Algorithm uses simulated Darwinian evolution
- Within 4 weeks, ARC can redesign and deliver a new evolved prototype





Evolved X-Band ST5 Antennas Flown and validated

Questions?